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Predicting Individual Differences in Hypothesis Generation

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Two experiments were performed to determine the extent to which individual differences in hypothesis generation could be predicted. In the first experiment, several published tests of creativity were used as predictors of hypothesis generation ability. The Alternate Uses test was the best predictor

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of hypothesis generation perrformance. In a second experiment, measures of achievement, general mental ability, and information were included with Alternate Uses as predictors of performance. Again Alternate Uses was the best predictor of performance. Several variants of the Alternate Uses test were also employed to isolate the components of hypothesis generation. It was found that two components were involved: retrieval of implicit dimensions of the objects and retrieval of uses when the dimensions are explicitly provided. The latter component was found to be by far the most important. It was concluded that good hypothsis generators have skills that enable them to effectively retrieve information stored in memory.

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Predicting Individual Differences in Hypothesis Generation

Hypothesis generation is the cognitive process by which alternative explanations or hypotheses are created to account for information or data and is a skill that has received little attention. A physician, for example, should generate plausible disease possibilities or diagnoses from the many diseases that a patient with a particular symptom complex might have. An average automobile driver may also generate a number of hypotheses which may explain why his car malfunctions. Hypothesis generation can be an important cognitive process whenever the decision maker is faced with uncertain or equivocal data where multiple hypotheses are possible. In this situation it is desirable that a decision maker be able to generate a hypothesis set which includes the true hypothesis.

There are at lease two important phases in the hypothesis generation process. Hypotheses are rarely created "de novo", rather they are usually retrieved from memory. Furthermore, hypotheses are also assessed for plausibility after retrieval, and implausible hypotheses are discarded. The decision maker then uses the set of plausible hypotheses as an input to the actual decision process.

A model of hypothesis generation has been proposed that postulates a multi-stage generation process that is controlled by an executive process (Gettys and Fisher, in press). According to this model, the executive process initiates a memory search to retrieve possible explanations for a set of data.

Hypotheses may be retrieved through direct associational linkages with the data or may be retrieved through indirect or mediated linkages. Once a hypothesis has been retrieved, it is checked for consistency with respect to any remaining data. Hypotheses that survive this initial logical consistency check may be subjected to further processing.

When one or more hypotheses have been retrieved, the executive process may transfer control to a process called plausibility assessment. This process consists of a more thorough examination of the hypothesis than is provided by consistency checking. The plausibility of an individual hypothesis is assessed to determine if it is a plausible explanation for the data. If a hypothesis is found to be plausible, it is added to those hypotheses that the decision maker is currently entertaining. This collection of hypotheses is called the "current hypothesis set". The decision to continue the memory search process, or terminate the search is based on an assessment of the current hypothesis set. If the current hypothesis set is believed to be incomplete, the search continues.

Gettys, Fisher and Mehle (1978), and Gettys and Fisher (in press) have shown that although hypothesis generation performance is generally poor, there were large individual differences among decision makers. Many decision makers are poor hypothesis generators while others are fairly proficient, therefore it should be worthwhile to develop measures to predict the hypothesis generation performance of an individual. Furthermore, an understanding of the cognitive skills necessary for proficient hypothesis generation might allow remedial training for those who are deficient in these skills.

Two experiments were conducted to pursue these goals. The first experiment examined the utility of published tests of creativity in the application of predicting hypothesis generation performance. A second experiment refined the most promising of these measures, and examined several additional possible predictors of hypothesis generation.

For the first experiment, a survey was made of published creativity tests to identify those that might be used as predictors of hypothesis generation performance. Certain types of creative thought seem to share many common characteristics with good hypothesis generation. We were interested in examining the type of creativity often attributed to scientists and other problem solvers rather than artistic creativity. While the latter type of creativity is often characterized by uniqueness of thought and response, the former requires that the thought also be productive or useful (Mednick, 1962). Scientific creativity is similar to hypothesis generation in that both processes use convergent and divergent thinking to attain a solution to a problem. Scientists and other hypothesis generators use clues provided by available data to retrieve hypotheses from memory using divergent thinking. When hypotheses are retrieved from memory they are assessed for both consistency and plausibility using convergent thinking, and hypotheses must meet both criteria to be acceptable. Artistic creativity, on the other hand, operates in a less constrained environment--it involves divergent thought that leads to many solutions or ideas.

For these reasons we chose four tests of creativity which we believed captured some of the essence of unusual but productive thought. The Alternate Uses test

(Christensen, Guilford, Merrifield, and Wilson, 1960) was chosen as a predictor because it required subjects to think of uses other than the ordinary one for a common object, while allowing creative people to produce productive, logical uses rather than fantastic or unreasonable ones. The Remote Associations Test (Mednick and Mednick, 1967) was also used because subjects who do well on this test can recognize nonobvious remote semantic relationships. This is a quality that should also be a component of good hypothesis generation. A subtest of the AC Test of Creative Ability, similar to Alternate Uses, which we called "Possible Reasons" (AC Spark Plug Division, General Motors Corp., 1953), was used because it was quite similar to a hypothesis generation task; subjects were provided with a description of a correlational relationship between objects or occurrences (for example, "corn and tomatoes grow better if they are planted in the same field than if they are planted separately") and were required to think of all possible reasons to explain why this relationship might exist.

Another test called "Cards" was developed to tap the subjects' divergent inductive reasoning capabilities as divergent induction could also be a component of hypothesis generation. In this task, subjects were asked to discover all possible rules that might have been used to generate a sequence of four playing cards.

Two types of tasks measuring hypothesis generation ability were used as criterion variables. Both tasks required subjects to generate all possible hypotheses that were consistent with the data provided by the experimenter. In one task, the Hypothesis Generation task, the data were characteristics of States of the Union, animals, occupations or academic majors. Subjects were

asked to generate as many possible instances for each category that were consistent with all of the data. In a second task, the Geography task, subjects were provided with maps of four existing geographical locations as well as three pieces of additional information about each location and were asked to think of all possible identities for each location. The process of using the available data to infer possible hypotheses about the way the land areas were utilized was believed to be a more realistic approximation of the hypothesis generation process used in everyday life. To some degree the Geography task simulates the cognitive processing used by intelligence analysts or photo interpreters. Both tasks require the subject to retrieve possible hypotheses from memory, and examine them to insure that they are consistent with all of the data.

In addition, it seems reasonable that the amount of information available in memory would influence the ability to generate hypotheses; consequently we included a task to measure the amount of specific information possessed by a subject about the particular Geography and Hypothesis Generation problems. The amount of information known by subjects was roughly assessed by asking the subjects to rate the plausibility of good, medium, and poor hypotheses for the particular problems encountered earlier. They were also allowed the opportunity to choose up to three hypotheses from the available list to add to their original hypothesis set. We hypothesized that if subjects have considerable information and are creative, they should do well on the criterion tasks. If they have considerable information and moderate to low creative abilities, they should do moderately well on the criterion tasks, but not as well as those who have high creative abilities. However, creative potential

should be of little use in the hypothesis generation tasks for subjects having little information.

Experiment 1

Method

Subjects. The 99 subjects who participated in Experiment 1 were introductory psychology students who received class credit for their participation. Data from two additional subjects were discarded because one subject did not return to the second session, while the other did not understand the instructions for one of the tests.

Details of the tests in the test battery. There were four categories of tests administered to the subjects. These categories included 1) Criterion measures of hypothesis generation performance, 2) Tests of creativity, 3) An inductive reasoning task, and 4) Tests of information. These tests are described below.

1) The two criterion tests were the "Hypothesis Generation" test and the "Geography" test, which were described earlier.

On the Hypothesis Generation test, subjects were asked to list as many hypotheses as possible in response to an item question such as "List as many States as you can that are noted for the following products or industries: A. Beef, B. Fish, and C. Aerospace Industry." The hypothesis generation test consisted of eight items. Two of the items contained hypotheses of states noted for products and industries; two items contained hypotheses of animals

based on their physical characteristics, two of the items contained hypotheses of skilled occupations based on tradesman's tools, and two of the items contained hypotheses of possible academic majors at the University of Oklahoma based on classes that an OU student had taken.

The Geography test consisted of a map and three additional pieces of information. The task of the subject was to generate possible hypotheses for an unidentified area on the map that were consistent with the map and the additional information. An example Geography problem is shown in the method of Experiment 2. The Geography test consisted of four problems.

Both of the criterion hypothesis generation tasks were scored similarly by first collecting all hypotheses generated by the subjects. A team of two experimeters then rated each hypothesis for consistency. For the "Hypothesis Generation" task, responses were rated either 'consistent' or 'inconsistent' and the corresponding hypothesis was then given either 1 or 0 points, depending on its assigned rating. For the "Geography" task, the responses were rated using a three point scale. Hypotheses that were consistent with all of the available data were given 2 points, hypotheses that were consistent with all but one piece of data were given 1 point, and hypotheses that were inconsistent with more than one piece of data were given zero points. Each hypothesis generated by a subject was scored using one of the scales described above. The subject then received one score for each of the two criterion tasks that consisted of the sum of the points earned for each hypothesis generated on each problem of the two tasks.

2) The creativity measures were the Alternate Uses Test, the Remote Associatons

test, and the "Possible Reasons" test.

On an Alternate Uses problem, subjects attempted to think of all practical uses for a common household object (i.e. a safety pin) that were not the usual use of that object (i.e. pinning together pieces of cloth). There were five problems of this type on the Alternate Uses test. The uses generated by subjects were independently scored by two experimenters who assigned one point for each appropriate answer. An inter-rater reliability coefficient was obtained to check the consistency of evaluations of the scorers.

Each problem on the Remote Associations Test consisted of three adjectives which were all remotely associated with a single noun. For example, "blue", "rat", and "cottage" are all associated with the noun "cheese". Subjects were required to write down a single response for each problem that was associated with all of the adjectives. Fifteen of these problems were included on the Remote Associations Test. A list of the correct responses was available for the RAT. A subject's score on this test consisted of the total number of correct responses.

Each problem on the "Possible Reasons" test consisted of a statement proposed as fact. An example problem follows: "Babies born in the months of October and November have better bones, on the average, than those born in the other ten months of the year." Subjects were asked to write down as many explanations for each statement as they could. Five such problems were included on this test. Two experimenters independently scored each response. Two points were given for a good response, that is, one that was highly plausible. One point was given for a fairly plausible response, and no points were given for

completely implausible responses. A subject's score on this test consisted of the sum of the points earned on all problems.

The creativity tests were administered in an abbreviated form in order to limit the amount of time that subjects must spend in the experiment and insure a high return rate.

3) The test of inductive reasoning utilized a sequence of four playing cards. Subjects were to examine the sequence and write down all possible rules that might account for that sequence. For Example, the sequence might be a 10, 4, 8, and 6 of clubs, in that order. Possible rules for this sequence might be "Each card is a club, each card is black, high-low-high-low, the sum of the first two cards is equal to the sum of the last two cards", etc. Three similar problems were included on the "Cards" task. The validity of responses was easily assessed, so only one experimenter scored responses for this task. Subjects received one point for each valid response. A subject's score on this task was the sum of the points received for each problem.

4) There were two tests measuring the amount of information possessed by subjects.

The first was the Hypothesis Generation Information test. For this test, subjects saw the same eight problems they had previously seen on the criterion Hypothesis Generation test. For this administration, however, nine possible hypotheses followed the problem. Three of these hypotheses were good, that is, consistent with all of the data, three were medium, that is, consistent with all but one piece of data, and three were poor, that is, consistent with less than two of the three pieces of data. The subjects had two tasks to perform.

The first was to rate the quality of the hypotheses using a five point scale. If the subject gave a hypothesis 5 points, it was considered to be "good", while a rating of 1 was considered to be "bad". The second task of the subjects was to compare our proposed hypotheses to the list of hypotheses they had generated earlier. If they wished to add any of our hypotheses to their list, they could indicate their desire to do so by making a check mark in the box located next to the particular hypothesis.

This test was scored by one experimenter who computed one score for each subject. The Information score was computed by taking the difference between the sum of the points assigned by the subject to the "good" hypotheses and the sum of the points assigned by the subject to the "bad" hypotheses. The best score a subject could get using this method was 12 points; 15 points for assigning a "5" to each of the "good" hypotheses minus 3 points for assigning a "1" to each of the "bad" hypotheses. The worst score was -12 points. A subject's score on this part would be the sum of the points for each of the eight problems.

The Geography Information task closely resembled the Hypothesis Generation Information task. In this task, subjects also rated the quality of nine hypotheses provided by the experimenters, and indicated whether they would like to add any of those hypotheses to the list of hypotheses they had generated earlier. There were four of this type of problem, each one corresponding to a particular Geography problem found in the criterion task.

The scoring methods used for this task were identical to those described for the Hypothesis Generation Information task. In addition, another three scores

were computed for each subject. These scores were designed to measure whether the subject realized that the "ground truth" hypotheses were good. The map for each Geography problem came from U.S. Census Tracts so that each problem had a "right" answer. Subjects received one point for a "Generation" score if they generated that right answer. They received one point for a "Recognition" score if they did not generate the right answer but recognized that it was a good answer. They received one point for a "Neither" score if they neither generated nor recognized the right answer. For each problem, then, subjects could receive only one point to be assigned to either the Generation, Recognition, or Neither category. Overall, the subject's Generation, Recognition, and Neither scores reflected the number of times they had done each of those activities over the entire set of Geography Information problems.

Testing Procedure. Subjects were tested in groups of about 20 during two one-hour sessions. The tasks were administered in the following order: Session 1: Geography Problems (15 minutes), Alternate Uses Test (10 minutes), Remote Associations Test (15 minutes), Geographical Information Test (10 minutes). Session 2: Hypothesis Generation Task (17 minutes), "Cards" Inductive Reasoning Test (10 minutes), "Possible Reasons" (10 minutes), Hypothesis Generation Information Test (12 minutes).

Results and Discussion

Correlations between creativity measures and hypothesis generation performance. A correlational analysis was performed to determine the relationship between tests of creativity and hypothesis generation performance.

The matrix of correlations between the predictor and the criterion variables is shown in table 1.

(Insert table 1 about here)

Two of the tests of creativity were noticeably related to hypothesis generation performance. The Alternate Uses test correlated significantly with both hypothesis generation tasks. The correlation between Alternate Uses and the hypothesis generation task was .33 ($p < .001$) and the correlation between Alternate uses and the Geography task was .27 ($p < .006$). The Possible Reasons test correlated with the Geography task ($r = .29$, $p < .004$), but did not correlate well with the hypothesis generation task.

A second analysis was performed to examine the predictive relationship between the creativity tests and an equally weighted composite of the Hypothesis Generation test and the Geography test. Here also the Alternate Uses test was the best predictor ($r = .34$, $p < .0001$) and the Possible Reasons test was noticeably inferior ($r = .19$, $p > .05$).

<u>Predicting hypothesis generation performance using multiple regression</u>. A multiple correlation was calculated to determine the extent to which all of the predictor variables could predict hypothesis generation performance as measured by the composite score. The multiple correlation was .477 which was significantly different from 0, ($F = 4.63$, $p < .001$). We then compared this model to a reduced model formed by eliminating predictor variables that were

TABLE 1

INTERCORRELATION MATRIX FOR EXPERIMENT 1

	AU	CARDS	PR	RAT	GI	HGI	GE	HG
AU	1.0	.30	.28	.18	.10	-.05	.27	.33
CARDS	.30	1.0	.29	.19	.13	.09	.14	.02
PR	.28	.29	1.0	.25	.14	.03	.29	.06
RAT	.18	.19	.25	1.0	.26	.12	.21	.12
GI	.10	.13	.14	.26	1.0	.16	.05	-.02
HGI	-.05	.09	.03	.12	.16	1.0	.08	.11
GE	.27	.14	.29	.21	.05	.08	1.0	.12
HG	.33	.02	.06	.12	-.02	.11	.12	1.0

AU=ALTERNATE USES TEST

CARDS=CARD TASK

PR=POSSIBLE REASONS TEST

RAT=REMOTE ASSOCIATIONS TEST

GI=GEOGRAPHICAL INFORMATION TEST

HGI=HYPOTHESIS GENERATION INFORMATION TEST

GE=GEOGRAPHY TEST

HG=HYPOTHESIS GENERATION TEST

weakly related to the criterion score. We found that a reduced model containing only the Alternate Uses test was statistically indistinguishable from the full model containing all the predictor variables. This result suggests only the Alternate Uses test need be employed as a predictor of hypothesis generation, and that this variable is by far the best predictor of hypothesis generation performance of the six variables studied.

The conclusions that can be drawn from this series of analyses are simple, and somewhat negative. First, only the Alternate Uses test, among the three creativity tests, predicts hypothesis generation performance. Secondly, our measure of the subjects' information was not a good predictor of hypothesis generation performance. This result suggests that being able to categorize hypotheses in terms of their consistency with the data is not related to hypothesis generation performance as measured by our two criterion measures. This result is consistent with the explanation that the major difficulty that subjects have in hypotheses generation is memory retrieval, and that the ability to assess hypotheses is not nearly as potent a predictor of hypothesis generation performance as the ability to retrieve hypotheses from memory. This effect also could be due to the low difficulty of the information task. The task required that subjects respond to hypotheses that differed grossly in respect to their suitability; the subjects may have performed fairly consistently on this task, and differences between subjects may have been due to characteristics such as motivation and care in responding accurately to all the questions.

Thirdly, the "Cards" test which was designed to measure divergent inductive

reasoning capabilities did not correlate noticeably with either of the criterion tasks. Here also individual differences in retrieval from memory may have been far more important than inductive reasoning.

The largely negative results of Experiment 1, where only the Alternate Uses test seemed to be related to hypothesis generation, may be due to a number of factors. First, Experiment 1 was designed to survey a large number of predictors, and we were not able to use a large number of items in each predictor for reasons of time. Therefore, the correlations which were obtained may have been reduced by the unreliability of the limited measures we obtained. Second, we noticed that the inter-item reliabilities in our criterion tasks were low, suggesting that the items were not necessarily measuring the same abilities. Consequently, we decided to pick the most promising of the predictor variables and study it in more detail while simultaneously improving the reliability of the criterion measure.

Experiment 2

The Alternate Uses test was found to be the best predictor of hypothesis generation performance in Experiment 1. There may be several component skills which influence performance on this test that are also important in hypothesis generation. Therefore, Experiment 2 was conducted partially to identify the relative importance of these components.

Consider the processes which might be used to generate alternate uses for a safety pin. A safety pin is a physical object which can be characterized along a number of dimensions, such as it is spring steel, it is sharp, it conducts electriciy, and it is fire resistent. The fact that it is sharp and can be

sterilized in a match flame suggests that it can be used for minor surgery, such as for removing a splinter. It can serve as a makeshift fishhook because it is spring steel, is sharp, and is hook-shaped. These dimensions may therefore serve as implicit retrieval cues for a memory search, and the ability to recall dimensions may be one component which is important for this task.

Retrieval of uses from memory is a second component that logically must be involved in hypothesis generation. Previous research (Gettys and Fisher, in press; Gettys, Fisher and Mehle, 1978) has identified this ability as being critically important. In the Alternate Uses test, the subject must be able to make a thorough search of memory in order to retrieve the alternate uses. This search may or may not be based on the implicit retrieval cues that an analysis of an object by its physical dimensions provides.

Hypothesis generation may also involve the same two components 1) retrieval of properties or characteristics of some object or entity, and 2) searching memory for hypotheses. In the Geography task maps are provided which identify an area that is surrounded by an unknown area. In generating hypotheses for the unknown area, the subject should exploit the implicit information created by the identification of the surrounding areas. For example, if the unknown area is surrounded by an area identified as residential, then it is unlikely that the unknown area will be used for activities that are considered noxious in a suburban area such as a stockyards or a racecar track. (An example Geography problem is shown in detail in the method section.)

Retrieval from memory is the second component, and in the Geography task, the

subject retrieves hypothesized uses for the unknown area from either the explicit information provided by the problem or the implicit information that they infer from the explicit information.

With these ideas in mind, two additional versions of the Alternate Uses Test were designed which were hoped to be relatively pure measures of either 1) retrieval of the properties or characteristics of an object or 2) retrieval of hypotheses from implicit or explicit cues. The original Alternate Uses test was assumed to involve both components to some degree. A second version of Alternate Uses was developed which measured the ability of the subjects to retrieve the implicit dimensions of an object. The third version of Alternate Uses provided the dimensions of the object to the subject, thereby making them explicit, and so measured the ability to retrieve additional hypotheses from these dimensions. By examining the extent to which these three versions of the Alternate Uses test predict hypothesis generation perfomance, the relative importance of the two proposed components in hypothesis generation can be assessed.

A second reason for conducting Experiment 2 was to increase the reliability of the predictor and criterion measures. The Alternate Uses test, which had been administered in an abbreviated form during Experiment 1 was doubled in length. Because the Alternate Uses test was found to predict performance as well as a linear combination of all the predictors from Experiment 1, for the second experiment the remaining creativity tests were discarded from the battery of predictors. The Hypothesis Generation test was discarded from the set of criterion variables because of low inter-item correlations; this test evidently

was not a pure measure of hypothesis generation. The remaining criterion test, the Geography task, was doubled in length, and ambiguities in some items were corrected.

A third reason for conducting Experiment 2 was to examine several potential predictors that were not included in Experiment 1 for reasons of time. These predictors were incorporated into Experiment 2 so that their relationship to hypothesis generation could be determined. These predictors consisted of measures of achievement and general ability and measures of episodic memory. It was decided to include the Information scale of the WAIS as a measure of general mental ability and the Verbal, Quantitative, and Composite scores from the ACT test as measures of achievement. It is possible that these factors alone could account for hypothesis generation performance. Although creativity is supposed to be a process that is unrelated to intelligence (Anastasi, 1968), it has been found that correlations between Alternate Uses and other measures of general intelligence lie between .2 and .3 (Guilford, Christensen, Merrifield, Wilson, 1978).

The decision to measure episodic memory was made because of the possibility that subjects' performance on Alternate Uses was based solely on their experiences, and that this experience was a limiting factor in memory retrieval. A search of episodic or situational memory (Tulving, 1972), would lead to the subjects retrieving object-uses that they have seen implemented in a particular situation. On the other hand, a search of semantic memory, which is not directly based on past experiences with the object, should lead to the subjects retrieving object uses that are instead created from a composition of ideas drawn from a more general memory store. A question included on parts One

and Three of the Alternate Uses test asked the subjects to indicate whether they had used or seen the object used in the way they had specified. Good hypothesis generators should use both semantic and episodic retrieval. For this reason, we would expect that people who do well on the Geography hypothesis generation task would show little dependence on episodic memory relative to those who do poorly.

Finally, the original test of information about the Geography problems was discarded and another was created in which fifteen possible hypotheses were presented for each of four of the Geography problems, and subjects were required to judge whether those hypotheses were consistent with the map and each written datum.

Method

Subjects. The 101 subjects included in the experiment were introductory psychology students who received class credit for participating in the experiment. No data collected in this experiment were discarded.

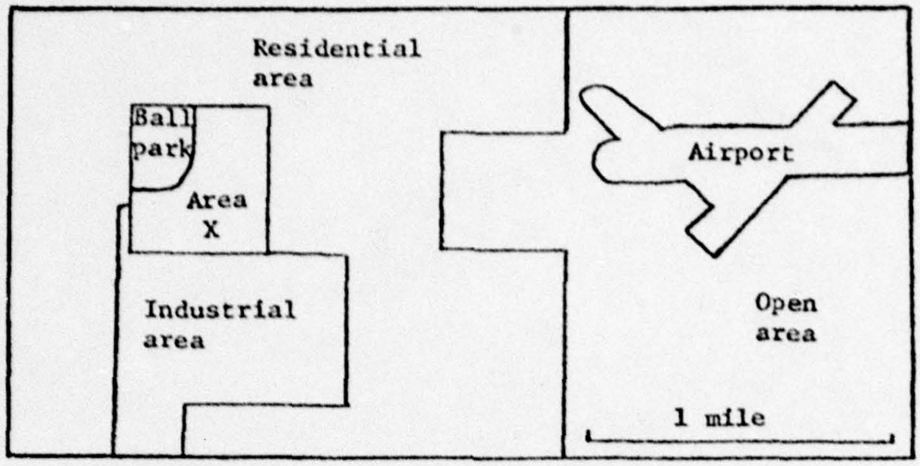
Details of the tests used in the test battery. There were four categories of tests administered to the subjects. These categories included 1) the criterion measure of hypothesis generation performance 2) Three versions of the Alternate Uses Test that measured retrieval of uses from implicit characteristics of the objects, retrieval of characteristics of the objects, and retrieval of uses when characteristics of the objects are provided, 3) achievement and general ability tests, 4) a test of information about the

criterion measure.

1) The sole criterion measure was the Geography task. More discussion of this measure is now warranted. An example of the Geography problems can be seen in figure 1. The maps used in these problems were copied from U.S. Census tracts. The additional written information that accompanied each map was created so that it was ambiguous enough to allow many hypotheses to be consistent. For this example, the actual location in figure 1 is a county fairgrounds; however, an amusement park, indoor arena or fieldhouse, community college, civic center or convention center, park, amphitheater or exposition center are examples of other consistent hypotheses. The expanded version of the Geography task contained eight problems.

(Insert figure 1 about here)

The Geography task was scored in the same manner as it was in Experiment 1. All responses for each problem were listed, then two experimenters rated each response using a three point scale. Again 2 points were given for hypotheses that were consistent with all the data, 1 point was given for hypotheses that were consistent with all but one piece of data, and zero points were given for hypotheses that were inconsistent with any more than one piece of data. A subject's score on the Geography task was the sum of the points received for each hypothesis for all problems.



ADDITIONAL INFORMATION ABOUT AREA X

1. Area X serves a county-wide area.
2. Seasonal events that attract a large number of people are scheduled in area X.
3. A wide variety of activities take place in area X.

Area X serves a definite purpose. Think of as many possible uses for area X as you can that are consistent with all the information provided (including the map) and list those uses below.

Figure 1. Sample problem from the Geography hypothesis generation task used in Experiment 2.

2) The three forms of the Alternate Uses test were the traditional Alternate Uses test that measured the ability to retrieve uses of common household objects from implicit data about those objects, another test that measured retrieval of characteristics of those objects, and a third that measured retrieval of uses when the characteristics were given. All three tests used the same ten common objects.

On the first Alternate Uses test (AU1) subjects generated as many uses as they could for common objects that were not commonly associated with the object. To measure the extent to which episodic memory is involved in retrieval, each problem of this test contained a question that asked whether the subject had used or seen the object used in the manner they had described. Subjects were instructed to answer that question by marking one of two boxes labelled 'Yes' or 'No' following each response.

For Alternate Uses 2, subjects listed all the properties or characteristics that they could for each of the same problems that appeared on the previous test.

Subjects were allowed to keep both of the previous forms of the Alternate Uses Tests they had already completed when they took Alternate Uses 3. The Alternate Uses 3 test was identical in form to Alternate Uses 1 except that a list of properties and characteristics was provided for each problem. Subjects were instructed to use the properties and characteristics listed on the test as well as those they had generated for Alternate Uses 2 to help them think of additional uses for the same objects they had seen on the previous two problems. Again, the measure of episodic memory was accomplished by asking the

subjects to mark one of two boxes labelled 'Yes' or 'No' in response to the question "Have you ever used or seen the object used this way?".

Two experimenters independently rated responses for each of these tasks. For the first task, a subject's AU1 score consisted of the sum of the appropriate responses that were generated for all problems. The episodic memory score (AUE1) was formed by computing the ratio of the number of uses on which the subject said 'Yes' in answer to the question designed to measure episodic memory retrieval to the total number of appropriate uses for all problems.

The score for Alternate Uses 2 (AU2) consisted of the sum of the number of appropriate characteristics generated for each of the ten problems.

The scoring used for Alternate Uses 3 (AU3) was similar to that used for AU1 in that it consisted of the sum of the number of appropriate uses generated for all problems. However in order for a response to be considered appropriate on AU3 it must not only be a legitimate use, but it must also be different from all responses generated for the corresponding problem on AU1. An episodic memory score identical to that used for AU1 was also computed for AU3.

All subjects received five scores for this series of tests. These scores were an Alternate Uses 1 score which measured the ability to retrieve uses using implicit characteristics of household objects, an Alternate Uses 1 Episodic memory score which measured the extent to which episodic memory had a role in this retrieval, an Alternate Uses 2 score which measured the ability to retrieve characteristics of the objects, and an Alternate Uses 3 score which measured the ability to retrieve uses when the characteristics were explicit, and an Alternate Uses 3 Episodic memory score which measured the use of

episodic memory in the Alternate Uses 3 test.

3) The measures of achievement and general ability were the Information scale of the WAIS and subjects' Verbal, Quantitative, and Composite scores on the ACT test. The Information scale of the WAIS consists of a series of questions measuring a subject's general knowledge about the world, for example "Why are dark clothes warmer than light clothes? or "How far is it from Paris to New York?. Twenty five of the questions from the WAIS information scale were used. A subject's score on this test consisted of the total number of correct answers given to all questions. The correct answers were obtained from the WAIS manual (Wechsler, 1955).

The Verbal, Quantitative, and Composite scores from the ACT test were chosen to measure achievement. The University of Oklahoma requires students to take the ACT test in order to be admitted to the University. These scores are considered to be predictors of grade point average, a measure of achievement in school. Subjects gave written permission during the experiment for experimenters to gain access to their ACT scores from school files. 4) The Geography Information test was used to measure the amount of information possessed by subjects. Problems on this test consisted of the same map and additional information that were found on the criterion Geography task. Fifteen possible hypotheses about each problem were presented to subjects. The task of a subject was to indicate whether the hypothesis was consistent with each individual datum (the map, additional information 1, additional information 2, and additional information 3) by writing a 'Y' or 'N' in a space next to the hypothesis that was under a column corresponding to the particular

datum. Each subject thus made 60 yes or no responses regarding their feeling of consistency or inconsistency about the fifteen proposed hypotheses. Four of this type of problem were used because the hypotheses proposed were some that had been generated on the Geography task of Experiment 1, which contained only four problems. A subject's score on this test consisted of the total number of correct judgments about consistency.

Testing procedure. Groups of 10 - 12 subjects were administered the tasks during a single two-hour session. The tasks were administered in the following order: Alternate Uses Part One (15 minutes), Alternate Uses Part Two (10 minutes, Alternate Uses Part Three (15 minutes), Geography Test (30 minutes), Geographical Information Test (20 minutes).

Results and Discussion

Predictors of hypothesis generation performance. A correlational analysis was performed between the predictor variables and the hypothesis generation criterion to assess the extent to which each predictor variable was correlated with the criterion variable. These results are shown in table 2.

(Insert table 2 about here)

By far the best predictor of hypothesis generation performance was the Alternate Uses test (AU1) which had a correlation of .51 ($p < .0001$) with the Geography test (GE). The increase in this correlation (as compared to the

TABLE 2

INTERCORRELATION MATRIX FOR EXPERIMENT 2

TEST	ACTV	ACTQ	ACTC	WAIS	GI	AU1	AU2	AU3	AUE1	AUE3	GE
ACTV	1.0	.48	.78	.52	.33	.15	.13	.24	-.22	-.08	.05
ACTQ	.48	1.0	.78	.43	.29	.28	-.02	.04	-.16	-.05	.03
ACTC	.78	.78	1.0	.64	.42	.13	.06	.18	-.18	-.14	.12
WAIS	.52	.43	.64	1.0	.34	.11	.18	.05	-.06	-.14	.24
GI	.33	.29	.42	.34	1.0	.11	-.03	.08	-.09	-.19	.21
AU1	.15	.28	.13	.11	.11	1.0	.17	.59	-.12	-.04	.51
AU2	.13	-.02	.06	.18	-.03	.17	1.0	.01	.11	.02	.24
AU3	.24	.04	.18	.05	.08	.59	.01	1.0	-.21	-.03	.48
AUE1	-.22	-.16	-.18	-.06	-.09	-.12	.11	-.21	1.0	.58	-.04
AUE3	-.08	-.05	-.14	-.14	-.19	-.04	.02	-.03	.58	1.0	-.05
GE	.05	.03	.12	.24	.21	.51	.24	.48	-.04	-.05	1.0

value of .27 obtained in Experiment 1) may be attributed to the increase in reliability of both Alternate Uses and the Geography test. This result indicates that hypothesis generation performance can be predicted from the Alternate Uses test, which is a simple "paper and pencil" test that can be administered in 15 minutes. With further development this correlation could undoubtedly be increased.

Next to be addressed was whether the Alternate Uses test predicts hypothesis generation performance over and above other potential predictors. The WAIS Information scale correlated .24 ($p < .016$) with GE. This scale was chosen because it is a good predictor of general mental ability, and tests of general mental ability typically correlate in the .2 to .3 range with tests of creativity. A partial correlation was calculated between Alternate Uses 1 and the Geography test holding the WAIS Information score constant. This partial correlation is a measure of the relationship between Alternate Uses and hypothesis generation that is not accounted for by intelligence or general ability. The partial correlaton was .286. An approximate test of significance was performed on that partial correlation, and was found to be significantly different from 0. This result suggests that the Alternate Uses measures the ability to generate hypotheses and that this ability is different from intelligence.

<u>The relative contribution of the component skills in hypothesis generation.</u> Several versions of the Alternate Uses test were created which reflected the several proposed components of hypothesis generation. Alternate Uses 2 (AU2) involves generating the <u>implicit</u> dimensions of an object, while Alternate Uses 3 (AU3) is a relatively pure measure of memory retrieval from explicit

retrieval cues. These two versions of the Alternate Uses test should separate the component abilities in the original Alternate Uses test. The "retrieval of implicit dimensions" component of Alternate Uses (AU2) correlated .24 ($p <$ .017) with hypothesis generation and the "retrieval of uses from explicit dimensions" component (AU3) correlated .48 ($p < .0001$). Clearly, the ability to retrieve information efficiently from memory accounts for more of the hypothesis generation performance than does the ability to retrieve dimensions, but both contribute significantly to hypothesis generation performance.

An analysis of variance was used to get a better understanding of the relative contribution of the "retrieval of implicit dimensions" component as compared to the retrieval of uses given dimensions" component. Subjects were assigned to high, medium and low AU2 groups by comparing their performance on AU2 to tertile scores which partitioned the AU2 scores into three equally numerous groups. Similarly, subjects were divided into high or low "retrieval of uses given dimensions" groups by comparing their performance on AU3 to the median score.

A two way Analysis of Variance with these AU2 and AU3 groupings as factors was performed with the Geography score as the dependent measure. Because there were an unequal number of subjects in each cell, the method of nonorthogonal Analysis of Variance suggested by Applebaum and Cramer (1974), in which patterns of significance are examined, was used. This method was implemented on the statistical package SAS in the manner suggested by Herr and Gaebelien (1978). Initially the interaction was nonsignificant, so the main effects could then be examined by performing "eliminating and ignoring" tests on each

variable of interest. The test of AU3 eliminating AU2, which tested whether there was any evidence of an AU3 effect over and above the AU2 effect present was significant ($F = 29.63$, $p < .0001$). The test of AU2 eliminating AU3, indicating any evidence of the effect of AU2 over and above the effect of AU3, was marginally significant ($F = 3.06$, $p < .0518$). While AU2 has an effect, as witnessed by this marginally significant result and its significant correltation with GE $r = .24$, $p < .017$), the "retrieval of uses given dimensions " component, AU3 is by far the most important variable. Because no interaction was found, it can be concluded that both components combine additively. However, the main effect results indicate that the performance on AU3 is by far the most important predictor. The contributions of the two proposed cognitive components to hypothesis generation are shown in figure 2, which plots the means from the Analysis of Variance.

(Insert figure 2 about here)

As can be seen in this figure, subjects who scored high in both components are substantially better hypothesis generators than subjects who scored low on both components. The superior hypothesis generator appears to be skilled in both generating the implicit dimensions of a problem, and in retrieving hypotheses based on these dimensions. These abilities do not appear to be related, as witnessed by the failure to find an interaction in the ANOVA, and by the correlation of -.04 between AU2 and AU3 (see table 2). This result suggests that these two components are independent skills or abilities. Of the two

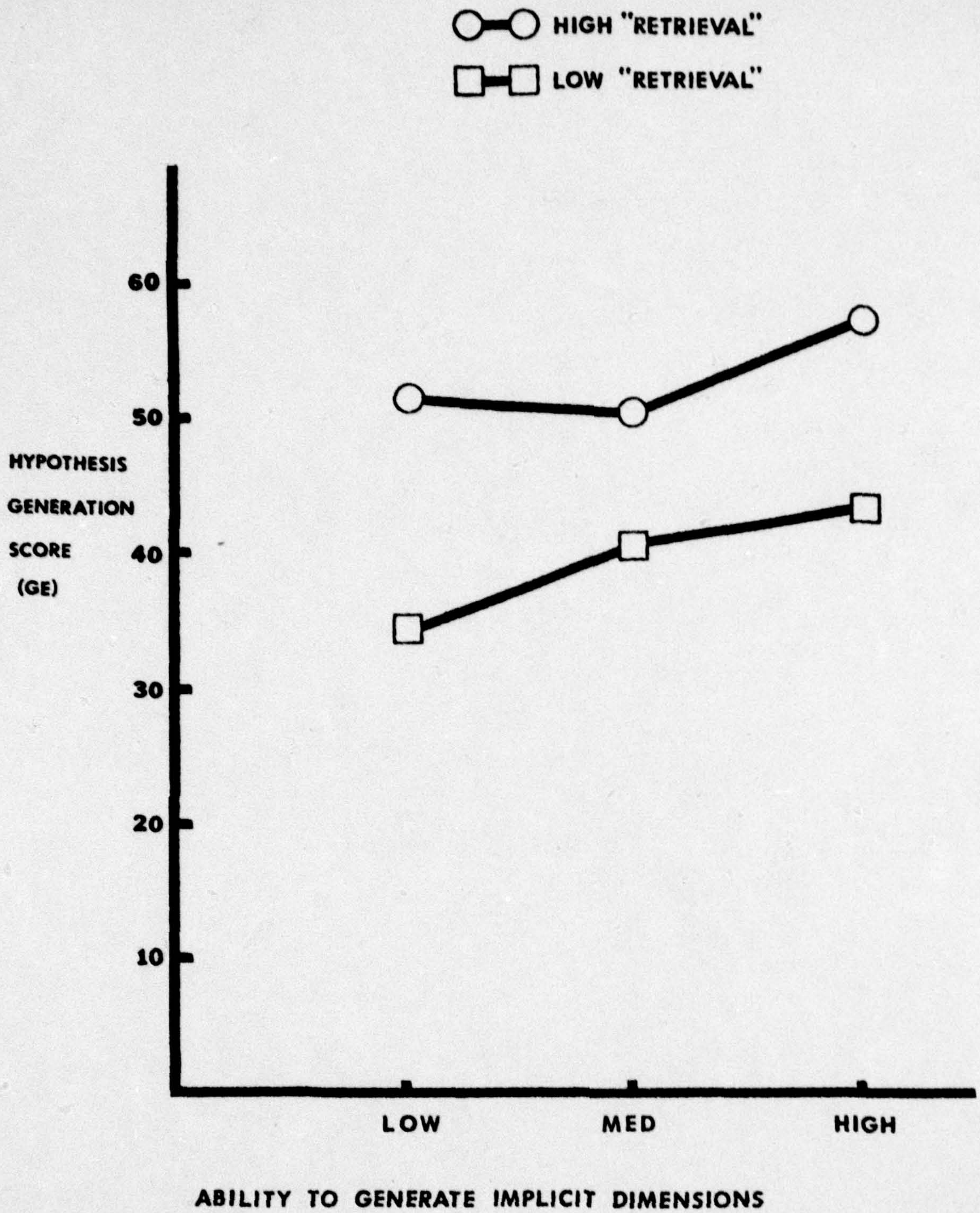


Figure 2. Mean hypothesis generation scores of subjects who scored differently on Alternate Uses 2 and Alternate Uses 3. Subjects were rated low, medium, or high in the ability to generate implicit dimensions on the basis of their Alternate Uses 2 score. The high "retrieval" group consisted of subjects who scored above the median on Alternate Uses 3, while the low "retrieval" group consisted of subjects who scored below the median on Alternate Uses 3.

components, retrieval of uses given dimensions seems to be the most important, but both components contribute significantly to performance.

The retrieval of hypotheses from memory probably does not depend on episodic memory, since the correlations between the episodic memory measures, AUE1 and AUE3, and hypothesis generation perfomance are -.04 and -.05, respectively. These results suggest that the ability to retrieve hypotheses is not heavily dependent on personal experience with these hypotheses in the past. A good hypothesis generator draws on the personal experiences in episodic memory, and on general information in semantic memory.

Finally, there was a significant correlation between the Geography Information score and the criterion ($r = .21$, $p < .04$). This implies that our measure of the amount of information possessed about a problem has a weak relationship to hypothesis generation performance. It may be, however, that the test of information measured the subject's hypothesis assessment abilities in judging a degree of consistency or inconsistency rather than measuring information alone. To test this, a revised Geography score was computed that consisted of the proportion of good responses, those receiving 2 points, to the total number of responses generated by each subject. The correlation of the GI score with this preditor was .27, a slight gain in predictive ability. It is more likely that this task was too difficult for the subjects, since it forced them to examine the consistency of implicit characteristics in an explicit situation. The *Geography Information* task, *therefore*, was probably not a pure measure of information possessed by subjects. The correlations between GI and the WAIS Information score [$r(GI,WAIS) = .34$, $p < .0005$], and GI and the ACT composite

score [r(GI,ACTC)= .42, $p < .0001$] provide additional evidence for this conclusion.

Component analysis of the predictors of hypothesis generation performance. A principal components analysis was used as a technique for summarizing the results of Experiment 2 to obtain a more global view of the results. A principal components analysis was performed on the intercorrelation matrix of the ten predictors and the Geography task. The purpose of this analysis was to summarize the nature of the abilities underlying the individual differences produced by these 11 measures. Specifically, we anticipated finding that the ability or abilities encompassing the individual differences in hypothesis generation would be unrelated to the abilities measured by the general achievement-ability tests (ACT-V, ACT-Q, ACT-C and WAIS-INFO). Also we hoped that the components structure would help clarify the nature of the relationships between the hypothesis generation task and the various measures based on the Alternate Uses test (AU1, AUE1, AU2, AU3, and AUE3).

Three principal components were extracted that accounted for 62 percent of the trace of the intercorrelation matrix. The initial, unrotated solution did not support a single factor solution; consequently, the three dominant components were rotated both orthogonally (Varimax) and obliquely (Promax). Inspection of the orthogonal and oblique solutions clearly indicated an orthogonal structure (i.e., uncorrelated components).

The Varimax component-structure matrix is shown in Table 3. In Table 3 component loadings (correlations between observed variables and components) less than .2 in absolute value have been suppressed. The resulting components

structure for the 11 variables has an unusually clear and unequivocal interpretation. Component 1 is defined by the three ACT measures, the WAIS Information test and the Geographical Information test. This first component we chose to call General Ability-Achievement. Notice that neither hypothesis generation nor the Alternate Uses measures have any appreciable correlation with the General Ability-Achievement component. Component 2 is defined by AU1 (the Alternate Uses Test administered under original instructions), AU3 (the Alternate Uses Test in which subjects generated uses of properties of the objects as well as a list of object properties explicitly provided by the experimenters) and GE (the total hypothesis generation score). From the nature of the three variables correlating most highly with Component 2, it is tentatively labeled Hypothesis Retrieval. The observed variables AU1, AU3 and GE all require a search of semantic memory for ideas consistent with certain inforiation or data provided to the subjects. The Hypothesis Retrieval component clearly does not subsume the ACT measures or the episodic memory abilities tapped by AUE1 and AUE3.

(Insert table 3 about here)

We suggest that Component 3 be named Episodic Memory since the observed variables correlating highest with this component are AUE1 and AUE3 (the measures of episodic memory derived from the Alternate Uses test). Recall that AUE1 and AUE3 are simply the proportion of uses listed by subjects in AU1 and AU3 that had actually been seen implemented in real situations. Notice also

TABLE 3

PRINCIPAL COMPONENTS ANALYSIS OF EXPERIMENT 2

VARIMAX ROTATED FACTOR MATRIX

	FACTOR 1 GEN. ABILITY-ACHIEVEMENT	FACTOR 2 HYPOTHESIS RETRIEVAL	FACTOR 3 EPISODIC MEMORY
ACTV	.81	*	*
ACTQ	.80	*	*
ACTC	.94	*	*
WAIS	.76	*	*
GI	.53	*	*
GE	*	.80	*
AU1	*	.84	*
AU3	*	.79	*
AU2	*	.31	.34
AUE1	*	*	.86
AUE3	*	*	.82

* CORRELATIONS LESS THAN .2 HAVE BEEN SUPPRESSED

that AU2, a measure of the ability to discern the basic properties of objects, correlated moderately with component 3. It may be that the determination of the properties of objects draws more heavily upon episodic memory as opposed to semantic memory.

The three component principal components analysis supported our prediction that hypothesis generation skills are not significantly related to general ability-achievement. Furthermore, the results of this analysis suggest that the ability common to successful performance on the hypothesis generation task and the Alternate Uses test may involve efficient searches where semantic memory is well developed and thoroughly searched.

Summary

The purpose of these two experiments was to begin an inquiry into individual differences in hypothesis generation. The first experiment was a survey designed to identify possible predictors of hypothesis generation performance. In this experiment, several tests of creativity which were believed to be related to hypothesis generation performance were examined, as well as several other predictors measuring inductive reasoning and information. It was found that only the Alternate Uses test, which measures creative thinking, was consistently related to hypothesis generation.

A second experiment was performed to examine the Alternate Uses test more closely, and to examine other potential predictors of hypothesis generation including general mental ability, achievement, and the relevance of episodic memory retrieval. It was proposed that there are several components to

successful hypothesis generation, one in which implicit dimensions of the object are retrieved, and one in which the hypothesis is retrieved using data that is explicitly provided. Various versions of the Alternate Uses test were constructed to measure these components, and results were obtained which suggest that the component of retrieving hypotheses when the information is provided is more important than retrieval of implicit dimensions, but that both factors influence performance through an additive relationship.

A components analysis suggested that general mental ablity and academic achievement are only weakly related to hypothesis generation and that hypothesis generation ability cannot be predicted adequately from these varibles alone. Rather, hypothesis generation ability seems to be more related to the ability to search memory effectively, and hypothesis generation performance can be predicted from the Alternate Uses test which measures this ability. The results also suggest that an individual's episodic memory is not the only source of hypotheses; that hypotheses are retrieved from both episodic and semantic memory.

A tentative picture of hypothesis generation performance is emerging from these results. As in other studies (Gettys and Fisher, in press, Gettys, Fisher, and Mehle, 1978) the critical variable appears to be primarily whether information that is stored in memory can be accessed. Hypothesis generation will not succeed unless this information can be retrieved, and evidently the most important variable is the efficiency of this retrieval process.

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